Total Maximum Daily Loads of Fecal Coliform for the Restricted Shellfish Harvesting Area of the Chester River in the Lower Chester River Basin, Southeast Creek Basin, and Middle Chester River Basin in Kent and Queen Anne's Counties, Maryland

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List of Abbreviations

BMP	Best Management Practice
BST	Bacteria Source Tracking
CFR	Code of Federal Regulations
cms	Cubic Meters per Second
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
EPA	Environmental Protection Agency
FA	Future Allocation
FDA	U.S. Food and Drug Administration
GIS	Geographic Information System
HEM-3D	Hydrodynamic and Eutrophication Model in 3 Dimensions
km	Kilometer
LA	Load Allocation
L_D	Load From Diffuse Sources
m	Meter
M_2	Lunar semi-diurnal tidal constituent
MACS	Maryland Agricultural Cost Share Program
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
mgd	Million Gallons per Day
ml	Milliliter(s)
MOS	Margin of Safety
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer Systems
MSSCC	Maryland State's Soil Conservation Committee
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSSP	National Shellfish Sanitation Program
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
VIMS	Virginia Institute of Marine Science
WLA	Wasteload Allocation
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment

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EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met (CFR 2006c).

The restricted shellfish harvesting area in the Chester River is located in portions of three 8-digit basins: Lower Chester River (basin number 02130505), Southeast Creek (basin number 02130508) and Middle Chester River (basin number 02130509). These three basins were all first identified on the 1996 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE). The Lower Chester River was listed as impaired by sediments (1996), nutrients (1996), fecal coliform in tidal shellfish harvesting portions of the basin (1996), toxics (2002), impacts to biological communities (2002, 2004), and bacteria in public beaches (2006). The Southeast Creek was listed as impaired by sediments (1996, 2002), fecal coliform in tidal shellfish harvesting portions of the basin (1996), impacts to biological communities (2002, 2004) and bacteria in public beaches (2006). The Middle Chester River was listed as impaired by sediments (1996), fecal coliform in tidal shellfish harvesting portions of the basin (1996), toxics (2002) and impacts to biological communities (2002, 2004, 2006). This document, upon EPA approval, establishes a TMDL of fecal coliform for the one restricted shellfish harvesting area in the Lower Chester River, Southeast Creek and Middle Chester River, hereafter referred to as the Chester River restricted shellfish harvesting area. Thus, the TMDL addresses all three listings for fecal coliform in the tidal shellfish harvesting portions of the three 8-digit basins. The listings for other impairments within the Lower Chester River Basin, Southeast Creek Basin, and Middle Chester River Basin will be addressed at a future date.

An inverse three-dimensional model was used to estimate current fecal coliform loads and to establish allowable loads for the restricted shellfish harvesting area in the Chester River watershed. The inverse model incorporates influences of freshwater discharge, tidal and density-induced transport, and fecal coliform decay, thereby representing the fate and transport of fecal coliform in the Chester River and its corresponding restricted shellfish harvesting area. The loadings from potential sources (human, livestock, pets, and wildlife) are quantified based on analysis of the bacteria source tracking (BST) collected in the Chester River over a one-year period.

The allowable fecal coliform loads for the restricted shellfish harvesting area were computed using both the median concentration water quality criterion for shellfish harvesting use of 14 Most Probable Number (MPN)/100ml, and the 90th percentile criterion concentration of 49 MPN/100ml for a three-tube decimal dilution. An implicit Margin of Safety (MOS) was incorporated into the analysis to account for uncertainty. The TMDLs developed for the restricted shellfish harvesting area in the Chester River mainstem located in Lower Chester River Basin, Southeast Creek Basin, and Middle Chester River Basin for fecal coliform are as follows:

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| Waterbody | Fecal Coliform TMDL [counts per day] | |
	based on Median Criterion	based on 90th Percentile Criterion
Chester River mainstem	2.552×10^{13}	3.754×10^{13}

The goal of TMDL allocation is to determine the maximum allowable loads based on known sources in the watershed that will ensure the attainment of the water quality standard. The TMDL allocations proposed in this document were developed based on the criterion requiring the largest percent reductions – here the 90th percentile criterion. The final TMDL requires a reduction of about 62.8% for the Chester River mainstem.

Once EPA has approved this TMDL, MDE will begin an iterative process of implementation, focusing first on those sources that have the greatest impact on water quality while giving consideration to the relative ease of implementation and cost. The source contributions estimated from the BST results may be used as a tool to target and prioritize initial implementation efforts. Continued monitoring will be undertaken by MDE's Shellfish Certification Division, and the data will be used to assess the effectiveness of the Department's implementation efforts on an ongoing basis.

1.0   INTRODUCTION

Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each state to develop a Total Maximum Daily Load (TMDL) for each impaired water quality limited segment (WQLS) on the Section 303(d) list, taking into account seasonal variations and including a protective margin of safety (MOS) to account for scientific uncertainty (CRF 2006c). A TMDL reflects the total pollutant loading of the impairing substance a waterbody can receive and still meet water quality standards.

TMDLs are established to achieve and maintain water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and/or numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

Fecal coliform are found in the intestinal tract of humans and other warm-blooded animals. Fecal coliform may occur in surface waters from point and nonpoint sources. Few fecal coliform are pathogenic; however, the presence of elevated levels of fecal coliform in shellfish waters may indicate recent sources of pollution. Some common waterborne diseases associated with the consumption of raw clams and oysters harvested from polluted water include viral and bacterial gastroenteritis and hepatitis A.

Fecal coliform are indicator organisms used in water quality monitoring in shellfish waters to indicate fresh sources of pollution from human and other animal wastes. When the water quality standard for fecal coliform in shellfish waters is exceeded, waters are closed to shellfish harvesting to protect human health due to the potential risk from consuming raw molluscan shellfish from contaminated waters. The U.S. Food and Drug Administration (FDA), rather than EPA, is responsible for food safety. Water quality criteria for shellfish waters are established under the National Shellfish Sanitation Program (NSSP), a cooperative program that involves states, industry, academic and federal agencies, with oversight by FDA. The NSSP continues to use fecal coliform as the indicator organism to assess shellfish harvesting waters (FDA 2003). The water quality goal of this TMDL is to reduce high fecal coliform concentrations to levels that meet the criteria associated with the shellfish harvesting designated use.

In both the 1996 and 1998 Maryland 303(d) Lists of Impaired Waterbodies, many shellfish listings were identified on a broad 8-digit watershed scale. These listings were further refined in the 2004 303(d) List. Since 2004, listings that are based on the shellfish water quality monitoring data are limited to the specific restricted shellfish harvesting areas within an 8-digit watershed (MDE 2006).

The restricted shellfish harvesting area in the Chester River is located in portions of three 8-digit basins: Lower Chester River (basin number 02130505), Southeast Creek (basin number

02130508) and Middle Chester River (basin number 02130509). These three basins were all first identified on the 1996 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE). The Lower Chester River was listed as impaired by sediments (1996), nutrients (1996), fecal coliform in tidal shellfish harvesting portions of the basin (1996), toxics (2002), impacts to biological communities (2002, 2004), and bacteria in public beaches (2006). The Southeast Creek was listed as impaired by sediments (1996, 2002), fecal coliform in tidal shellfish harvesting portions of the basin (1996), impacts to biological communities (2002, 2004) and bacteria in public beaches (2006). The Middle Chester River was listed as impaired by sediments (1996), fecal coliform in tidal shellfish harvesting portions of the basin (1996), toxics (2002) and impacts to biological communities (2002, 2004, 2006). This document, upon EPA approval, establishes a TMDL of fecal coliform for the one restricted shellfish harvesting area in the Lower Chester River, Southeast Creek and Middle Chester River, hereafter referred to as the Chester River restricted shellfish harvesting area. Thus, the TMDL addresses all three listings for fecal coliform in the tidal shellfish harvesting portions of the three 8-digit basins. The listings for other impairments within the Lower Chester River Basin, Southeast Creek Basin, and Middle Chester River Basin will be addressed at a future date.

Bacteria impairments for shellfish harvesting waters of the Chester River watershed are based on data from MDE's Shellfish Program used to classify shellfish harvesting areas. When fecal coliform criteria are not met, the area is classified as restricted or closed to harvesting. The criteria include both a median and a 90th percentile concentration requirements (COMAR 2006).

2.0   SETTING AND WATER QUALITY DESCRIPTION

2.1   General Setting

This report addresses the restricted shellfish harvesting area in the Chester River mainstem located on Maryland's Eastern Shore in Kent and Queen Anne's Counties, as shown in Figure 2.1.1. This restricted area is located in three 8-digit basins: Lower Chester River (basin number 02130505), Southeast Creek (basin number 02130508), and Middle Chester River (basin number 02130509). The Chester River is approximately 44.5 km in length and its width ranges from 30 to 500 m upstream and approximately 5.4 km at its mouth (where it flows into Chesapeake Bay). The portion restricted to shellfish harvesting has a length of 10.0 km and a drainage area of 195,548.2 acres (791.4 km^2).

The soil conditions in the Chester River watershed vary greatly from site to site. Soil ranges from well-drained to moderately well-drained. About 64% of the land in the watershed is farmland. Approximately 20% of the watershed exhibits moisture-related limitations in the watershed adjacent to the restricted area. Concentrated along local waterways are soils on slopes between 8% to 15% and soils that are excessively well-drained in the middle portion of the Chester River (DNR 2001). The dominant tide in this region is the lunar semi-diurnal (M_2) tide, with a tidal range of 0.55 m in the restricted portion of the Chester River with a tidal period of 12.42 hours (NOAA 2006). Please refer to Table 2.1.1 for the mean volume and mean water depth of this restricted shellfish harvesting area.

Table 2.1.1: Physical Characteristics of the Chester River Restricted Shellfish Harvesting Area

Restricted Shellfish Harvesting Area	Mean Water Volume [m^3]	Mean Water Depth [m]
Chester River Mainstem	28,725,257	3.19

The 2000 Maryland Department of Planning (MDP) land use/land cover data show that the watershed can be characterized as primarily rural for the Chester River, with 63% of the area being cropland and more than 24% being forest. The land use information in the Chester River Basin is shown in Table 2.1.2 and Figure 2.1.2. Residential urban land use identified in Table 2.1.2 includes low-density residential, medium-density residential, and high-density residential. Non-residential urban land use in this table includes commercial, industrial, institutional, extractive, and open urban land.
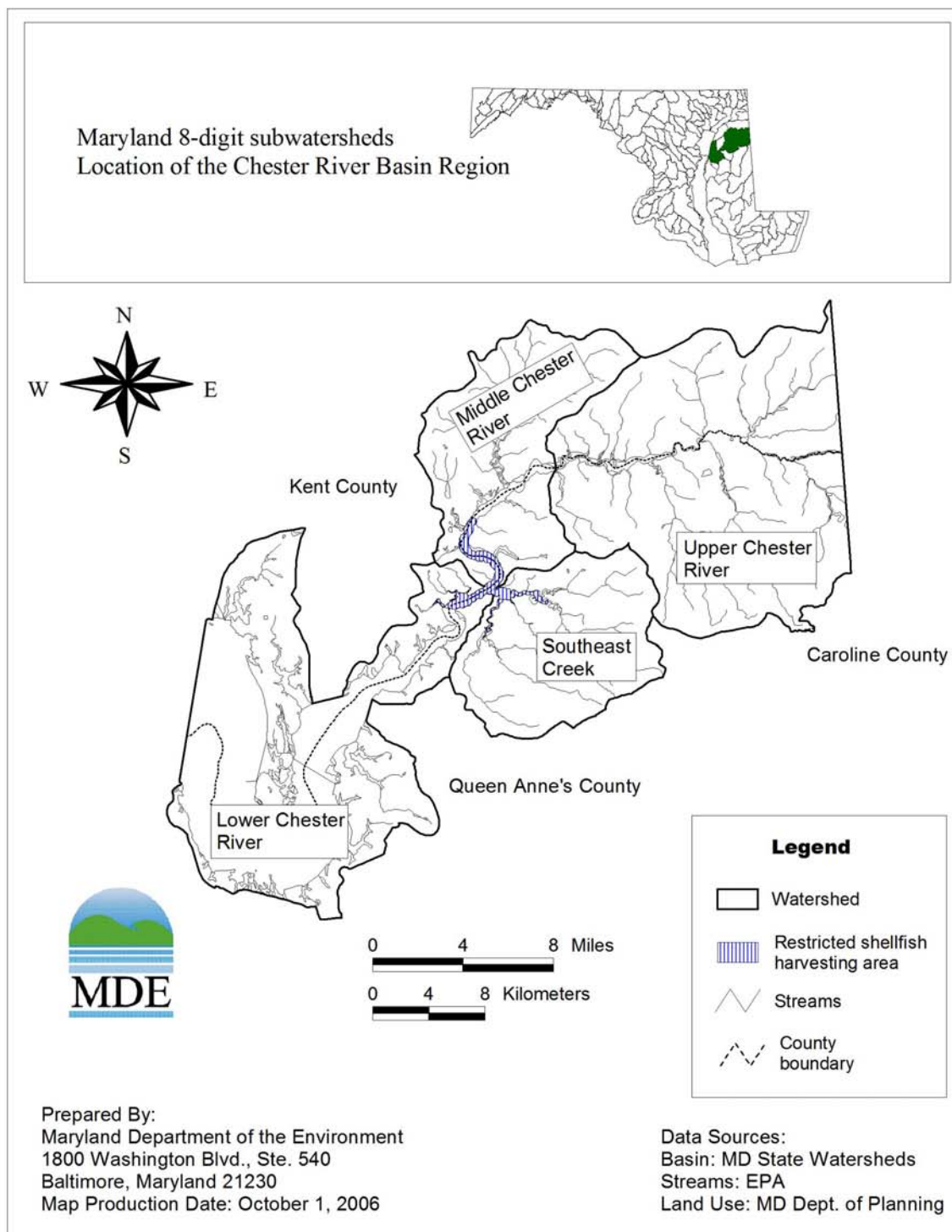
Figure 2.1.1: Location Map of the Chester River Basin

Table 2.1.2: Land Use Percentage Distribution for Chester River Watershed

Land Type	Acreage	Percentage
Residential urban[1]	7,676.6	3.93
Non-Residential urban[2]	2,003.1	1.02
Cropland	123,200.7	63.00
Pasture	1,277.3	0.65
Feedlot	1,272.4	0.65
Forest	47,788.9	24.44
Water	1,367.5	0.70
Wetlands	10,927.3	5.59
Barren	34.4	0.02
Totals	**195,548.2**	**100.00**

Notes: [1] Includes low-density residential, medium-density residential, and high-density residential.
[2] Includes commercial, industrial, institutional, extractive, and open urban land.
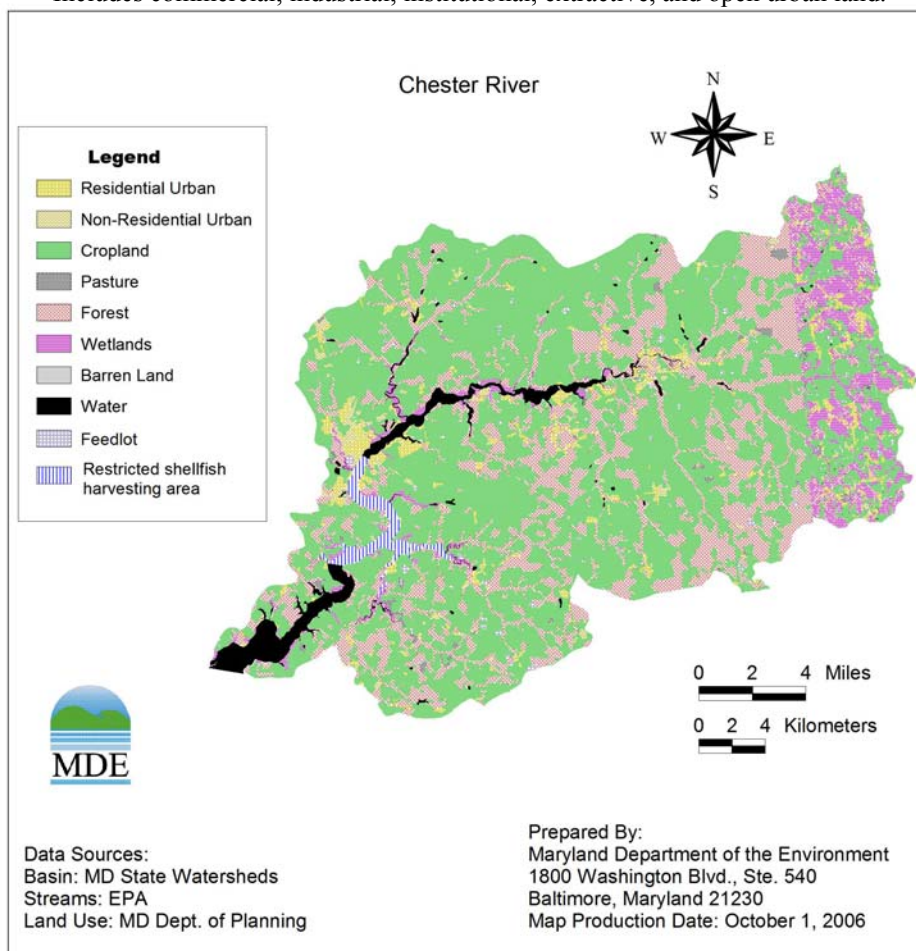
Figure 2.1.2: Land Use in the Chester River Basin

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2.2   Water Quality Characterization

MDE's Shellfish Certification Program is responsible for classifying shellfish harvesting waters to ensure oysters and clams are safe for human consumption. As discussed above, MDE adheres to the requirements of the National Shellfish Sanitation Program, with oversight by the U.S. Food and Drug Administration. MDE conducts shoreline surveys and collects routine bacteria water quality samples in the shellfish waters of Maryland to assure that Maryland's shellfish waters are properly classified.

MDE's Shellfish Certification Program monitors shellfish waters throughout Maryland. There is one shellfish monitoring station in the restricted shellfish harvesting area addressed in this report. The station identification and observations recorded during the period of June 2000 – June 2005 are provided in Table 2.2.1 and Figure 2.2.1 through Figure 2.2.2. A tabulation of observed fecal coliform values at the one monitoring station included in this report is provided in Appendix D.

Table 2.2.1: Location of the Shellfish Monitoring Station in Chester River

Station Location	Shellfish Monitoring Station	Obs. Period	Total Obs.	LATITUDE Deg-min-sec	LONGITUDE Deg-min-sec
Chester River mainstem	04-01-002	2000-2005	64	39 09 17.7	76 03 56.1
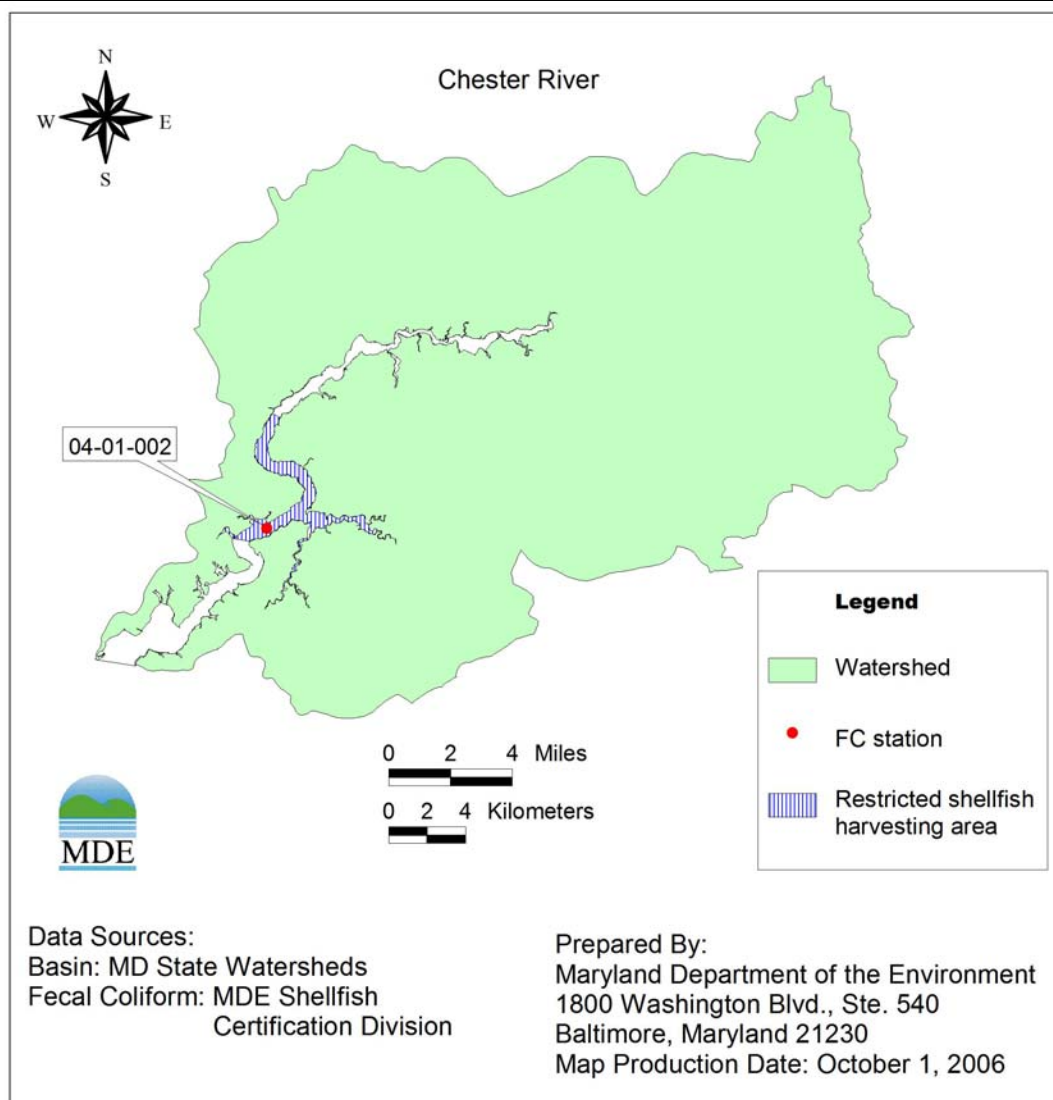
Figure 2.2.1: Shellfish Monitoring Station in Chester River

Figure 2.2.2: Observed Fecal Coliform Concentrations at Station 04-01-002
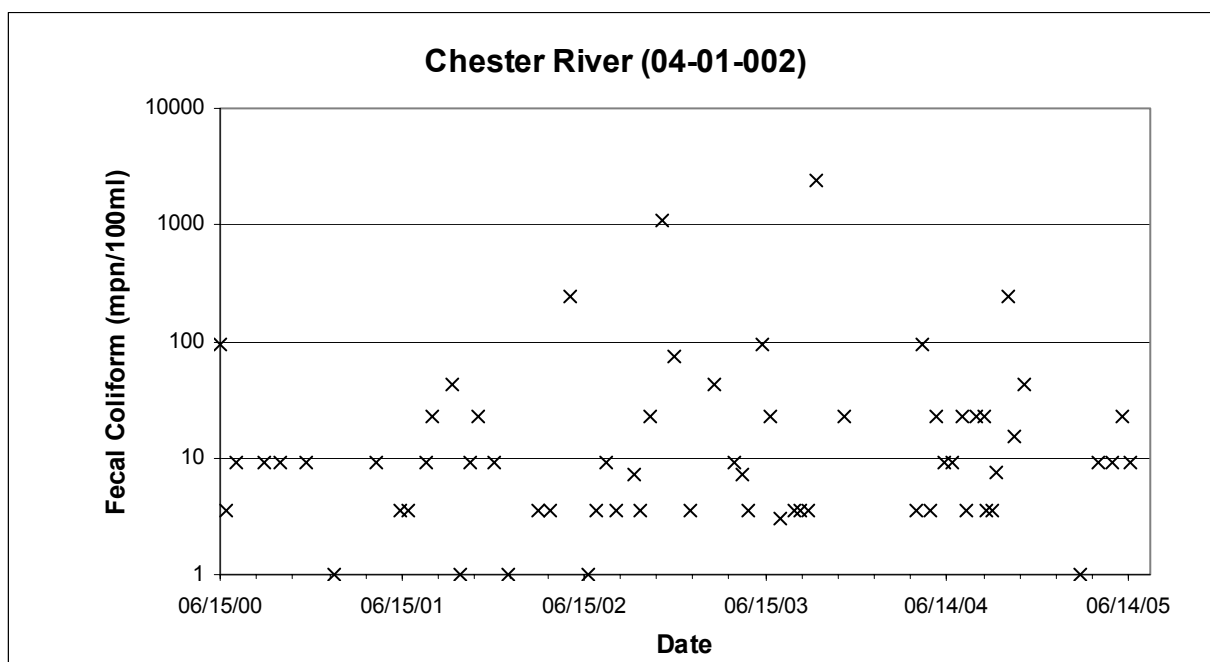
2.3   Water Quality Impairment

The fecal coliform impairment addressed in this analysis was determined with reference to Maryland's Classification of Use II Waters (Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting) in the Code of Maryland Regulations (COMAR), Surface Water Quality Criteria 26.08.02.03-3.C(2), which states:

> 2) Classification of Use II Waters for Harvesting.
>
> (a) Approved classification means that the median fecal coliform MPN of at least 30 water sample results taken over a 3-year period to incorporate inter-annual variability does not exceed 14 per 100 milliliters; and:
>
> (i) In areas affected by point source discharges, not more than 10 percent of the samples exceed an MPN of 43 per 100 milliliters for a five tube decimal dilution test or 49 MPN per 100 milliliters for a three tube decimal dilution test; or
>
> (ii) In other areas, the 90th percentile of water sample results does not exceed an MPN of 43 per 100 milliliters for a five tube decimal dilution test or 49 MPN per 100 milliliters for a three tube decimal dilution test (COMAR 2006).[1]

MDE updated and promulgated water quality criteria for shellfish waters in June 2004. Although bacteriological criteria for shellfish harvesting waters were unchanged, the update included the classification criteria required under the NSSP that previously was not included in COMAR. In 2005, MDE revised the use designations in COMAR as part of the Chesapeake Bay Program revision to reflect living resources based habitat needs, but did not change the fecal coliform criteria for shellfish harvesting waters or shellfish harvesting use designations.

Maryland water quality standards explicitly state the fecal coliform criteria as a median and 90th percentile of at least 30 water sample results taken over a 3-year period. Therefore, a requirement of a daily TMDL value is not appropriate. Rather, the TMDL refers to an average daily value that will ensure that the more stringent of the two criteria is met.

For this analysis, MDE is using routine monitoring data collected over a five-year period between June 2000 and June 2005. Most shellfish harvesting areas have been monitored routinely since before 1950 and, due to an emerging oyster aquaculture industry, there are a few shellfish harvesting areas that have less than five years worth of data. For the purpose of classifying shellfish harvesting areas, a minimum of 30 samples is required. For TMDL development, if fewer than 30 samples are available, current loads are estimated based on all of the most recent data. The assimilative capacity will be based on the approved classification requirements of a median concentration of 14 MPN/100 ml and a 90th percentile concentration of less than 49 MPN/100 ml.

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[1] Note that Maryland uses the three-tube decimal dilution test for fecal coliform bacteria monitoring purposes.

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The water quality impairment in the Chester River mainstem was assessed as not meeting the 90th percentile at its one monitoring station, Station 04-01-002. Descriptive statistics of the monitoring data and the requirements for the approved classification are shown in Table 2.3.1.

Table 2.3.1: Chester River Fecal Coliform Statistics (data from 2000-2005)

Area Name	Station	Median		90th Percentile	
		Monitoring Data	Criterion	Monitoring Data	Criterion
		MPN/100ml	MPN/100ml	MPN/100ml	MPN/100ml
Chester River	04-01-002	9.10	14	78.64	49

2.4   Source Assessment

Nonpoint Source Assessment

Nonpoint sources of fecal coliform do not have a single discharge point, but rather they occur over the entire length of a stream or waterbody. There are many types of nonpoint sources in watersheds discharging to the restricted shellfish harvesting area. The possible introductions of fecal coliform to the land surface are through the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. As the runoff occurs during rain events, surface runoff transports water and fecal coliform over the land surface and is introduced into surface waters. The deposition of non-human fecal coliform directly to the restricted shellfish harvesting areas may occur when livestock or wildlife have direct access to the waterbody. Nonpoint source contributions from human activities generally arise from failing septic systems and their associated drain fields as well as through pollution from recreational vessel discharges. The potential transport of fecal coliform from land surfaces to restricted shellfish harvesting waters is dictated by the hydrology, soil type, land use, and topography of the watershed.

In order to determine the sources of fecal coliform contribution and reduction needed to achieve water quality criteria and to allocate fecal coliform loads among these sources, it is necessary to identify all existing sources. MDE conducted sampling over a one-year period at one station in the Chester River using bacteria source tracking (BST) to identify sources of fecal coliform. The nonpoint source assessment was conducted by analyzing BST results to quantify source loadings from humans, livestock, pets, and wildlife.

In the Chester River basin, wildlife contributions, both mammalian and avian, are considered natural conditions and may represent a background level of bacterial loading. Livestock contributions, such as those from mammalian and avian livestock, mainly result from surface runoff. The watershed is predominately cropland and forest. According to land use information, the wildlife and livestock could be the dominant sources. Pet contributions usually occur through runoff from streets and land. Human sources mainly result from failure of septic

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systems. Figure 2.1.2 shows the land use categories in the watershed. Based on the analysis of BST data, livestock is the predominant bacteria source followed by pet, wildlife, and human sources. Forty-two percent (42%) of the water isolates were from unknown (unclassified) probable sources. Table 2.4.1 summarizes the source distribution based on BST data analysis. Detailed results of BST analysis are presented in Appendix B.

Table 2.4.1: Source Distribution Based on BST Data Analysis

Human	Livestock	Wildlife	Pets	Unknown
8.4%	20.0%	11.6 %	17.9%	42.1%

BST data analysis includes a statistical comparison of known sources collected in the watershed and compared with unknown source samples collected over the study period. The fecal coliform sources in water samples are unknown until matched with the library of known sources. The 42.1% unknown sources for BST analysis are those where no match was identified in the known library. They do not represent unknown sources in the sense that they cannot be identified, rather they represent a portion of the statistical analysis where no matches to the BST library were found (see Appendix B for details on BST used for this report).

Point Source Assessment

There are five municipal sewage treatment facilities that have permits regulating the discharge of fecal coliform to the Chester River: Chestertown Waste Water Treatment Plant (WWTP) with National Pollution Discharge Elimination System (NPDES) permit number MD0020010, Kennedyville WWTP (NPDES number MD0052671), Eastern Pre-Release Unit WWTP (NPDES number MD0023876), Church Hill WWTP (NPDES number MD0050016), and Worton-Butlerton WWTP (NPDES number MD0060585). The permits for flow discharges are, respectively, 0.9, 0.06, 0.02, 0.08, and 0.15 MDG. These municipal point sources have permits to discharge fecal coliform/E. Coli to the Chester River (or its tributaries). The permitted fecal coliform or E. Coli concentrations are 14 MPN/100ml (median for fecal coliform), 126 MPN/100ml (monthly log mean for E. Coli), 200 MPN/100ml (monthly log mean for fecal coliform), 14 MPN/100ml (median for fecal coliform), and 200 MPN/100ml (monthly log mean for fecal coliform), respectively. There are also two permitted industrial point sources: Velsicol Chemical Corp. (NPDES number MD0000345) and Chestertown Foods, Inc. (NPDES number MD0002232). Chestertown Foods, Inc. has a permit to discharge 0.204 MGD with a fecal coliform concentration of 200 MPN/100ml. The allocation of the permitted load from these point source facilities will be addressed in Section 4.7.

3.0   TARGETED WATER QUALITY GOAL

The overall objective of the fecal coliform TMDLs summarized in this document is to establish the maximum loading needed to ensure attainment of water quality standards in the restricted shellfish harvesting area in the Chester River mainstem. These standards are described fully in Section 2.3, Water Quality Impairment.

4.0   TOTAL MAXIMUM DAILY LOADS AND LOAD ALLOCATION

4.1   Overview

This section documents the detailed fecal coliform TMDLs and load allocation development for the restricted shellfish harvesting waters in the Chester River watershed. The required load reduction was determined based on data collected from June 2000 to June 2005. The TMDLs are presented as counts/day. Section 4.2 describes the analysis framework for simulating fecal coliform concentration in restricted shellfish harvesting waters in the Chester River. Section 4.3 addresses critical conditions and seasonality. The TMDL calculations are presented in Section 4.4. Section 4.5 provides a summary of baseline loads and Section 4.6 discusses TMDL loading caps. Section 4.7 provides the description of the waste load and load allocations. The margin of safety is discussed in Section 4.8. Finally, the TMDL equation is summarized in Section 4.9.

A TMDL is the total amount of a pollutant that a waterbody can receive and still meet water quality criteria, which in the case of this document would be Maryland's water quality criteria for shellfish harvesting waters. A TMDL may be expressed as a "mass per unit time, toxicity, or

other appropriate measure" (CFR 2006b). These loads are based on an averaging period that is defined by the specific water quality criteria for shellfish harvesting waters. The averaging period used for development of these TMDLs requires at least 30 samples and uses a five-year window of data to identify current baseline conditions.

A TMDL is the sum of individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, incorporating natural background levels. The TMDL must, either implicitly or explicitly, include a margin of safety that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and in the scientific and technical understanding of water quality in natural systems. In addition, when applicable, the TMDL may include a future allocation (FA) when necessary. This definition is denoted by the following equation:

$$TMDL = WLAs + LAs + MOS + (FA, \text{ where applicable})$$

4.2   Analysis Framework

In general, tidal waters are exchanged through their connecting boundaries. The tide and amount of freshwater discharged into the restricted shellfish harvesting area are the dominant forces that influence the transport of fecal coliform. The restricted area is located in the middle of the Chester River and it is influenced by both tide and freshwater input. The current distribution in the system varies as tidal and freshwater discharges change. In order to simulate the transport and fate of bacteria in the Chester River accurately, the 3-dimensional hydrodynamic and eutrophication model (HEM-3D) has been used for this study. The HEM-3D model is a general 3D model for environmental studies. The model simulates density and topographically induced circulation as well as tidal and wind-driven flows, and spatial and temporal distributions of salinity, temperature, and suspended sediment concentration, conservative tracers, eutrophication processes, and fecal coliform. For a detailed model description, the reader is referred to Park et al. (1995).

The Chester River is represented by a horizontal network of model grid cells. There are a total of 207 model grid cells in the modeling domain. To better simulate the stratification effect, three layers are used in the vertical. For this study, the model was calibrated for the tide and long-term mean salinity distribution. In order to address the standards of the median and 90th percentile fecal coliform concentrations, an inverse approach has been adopted here to estimate the loads from the watershed. The watershed is divided into 24 subwatersheds. The loads from each subwatershed are discharged into the river from the river's tributaries.

The model was forced by the M_2 constituent of the tide and the mean salinity concentration at the river's mouth. The long-term mean freshwater input estimated based on data from United States Geological Survey (USGS) gage station 01493500 was used. The discharges from subwatersheds are estimated based on the ratio of subwatershed area to the total drainage basin of the USGS station. The inverse method is used to estimate the existing load discharged from each subwatershed based on median and 90th percentile fecal coliform data obtained from

observations. The model is also used to establish the allowable loads for the river. Detailed modeling procedures are described in Appendix A.

4.3   Critical Condition and Seasonality

EPA's regulations require TMDLs to be "established at levels necessary to attain and maintain the applicable narrative and numerical WQS [water quality standards] with *seasonal variations* and a *margin of safety* . . . Determinations of TMDLs shall take into account *critical conditions* for stream flow, loading, and water quality parameters" (CFR 2006c). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The critical condition accounts for the hydrologic variation in the watershed over many sampling years, whereas the critical period is the time during which a waterbody is most likely to violate the water quality standard.

The 90th percentile concentration is the concentration that exceeded the water quality criterion only 10% of the time. Since the data used were collected over a five-year period, the critical condition requirement is implicitly included in the 90th percentile value. Given the length of the monitoring record used and the limited applicability of best management practices (BMPs) to extreme conditions, the 90th percentile concentration is utilized instead of the absolute maximum.

A comparison of the median values and the 90th percentile values against the water quality criteria determines which represents the more critical condition or higher percent reduction. If the median values dictate the higher reduction, this suggests that, on average, water sample counts are high with limited variation around the mean. If the 90th percentile criterion requires a higher reduction, this suggests an occurrence of high fecal coliform due to the variation of hydrological conditions.

The seasonal fecal coliform distribution for the one applicable monitoring station is presented in Appendix C. The results show the seasonal variability of fecal coliform concentrations. High concentrations occur in the months of September and November in the Chester River restricted shellfish harvesting area. The large standard deviations correspond to the high variability in concentration at this station, resulting in a high 90th percentile concentration, which indicates that exceedances may occur only during a few months of the year.

Similar to the critical condition, seasonality is also implicitly included in the analysis due to the averaging required in the water quality standards. The MDE shellfish-monitoring program uses a systematic random sampling design that was developed to cover inter-annual variability. The monitoring design and the statistical analysis used to evaluate water quality attainment therefore implicitly include the effect of seasonality. By examining the seasonal variability of fecal coliform, the highest fecal coliform concentration often occurs during the few months of the year that correspond to the critical condition. If loads under the critical condition can be controlled, water quality attainment can be achieved.

4.4 TMDL Computation

According to the water quality standards for fecal coliform in shellfish waters, computation of a TMDL requires analyses of both the median and 90th percentile scenarios.

Routine monitoring data were used to estimate the current loads. Both the median and the 90th percentile analyses have been performed. There is only one routine monitoring station located inside the restricted area and two routine monitoring stations located on the downstream side of the restricted area and inside the model domain. In order to estimate the existing condition of fecal coliform along the Chester River, a short-term observation was conducted along the river from autumn to winter of 2005 (September to December). These data were used to determine existing loads together with the data from three long-term routine monitoring stations. The load from each subwatershed was discharged into its corresponding segment of the river. The inverse method was used to compute the watershed loads discharged into the river based on the best match of observations and model simulation of fecal coliform concentrations in the river. Detailed computation is presented in Appendix A. The total loads are reported in Table 4.4.1 and Table 4.4.2. Detailed results by subwatershed are also listed in Appendix A.

The allowable load is calculated using the water quality criteria of a median of 14 MPN/100ml and a 90th percentile of 49 MPN/100ml. The 3-D model was used to compute the allowable load for each subwatershed by reducing the existing loads from the watershed so that the fecal coliform concentrations in the receiving water meet the appropriate water quality standards. The total loads discharged into the river are the summation of loads discharged from each subwatershed. For the Chester River mainstem restricted area, the 90th percentile criterion is not met at its one monitoring station. The load reduction needed for the attainment of the criteria is determined as follows:

$$\text{Load Reduction} = \frac{\text{Current Load} - \text{Allowable Load}}{\text{Current Load}} \times 100\%$$

The TMDL calculations are presented in Appendix A. The calculated results are listed in Table 4.4.1 and Table 4.4.2.

Table 4.4.1: Median Analysis of Loads and Estimated Load Reduction

Area	Mean Volume M³	Fecal Coliform Median Criterion MPN/100mL	Current Load counts/day	Allowable Load counts/day	Required Percent Reduction (%)
Chester River mainstem	28,725,257	14	2.552E+13	2.552E+13	0.00

Table 4.4.2: 90th Percentile Analysis of Loads and Estimated Load Reduction

Area	Mean Volume M³	Fecal Coliform 90th Percentile Criterion MPN/100mL	Current Load counts/day	Allowable Load counts/day	Required Percent Reduction (%)
Chester River mainstem	28,725,257	49	1.009E+14	3.754E+13	62.79

4.5 Summary of Baseline Loads

For the TMDL analysis period, from June 2000 to June 2005, the calculated baseline (current) loads of fecal coliform from all sources in the restricted shellfish harvesting area of the Lower Chester River basin are summarized in Table 4.5.1 (see also Table 4.4.1 and Table 4.4.2 above).

Table 4.5.1: Summary of Baseline Loads

Waterbody	Fecal Coliform Baseline Loads [counts per day]	
	Median Analysis Scenario	90th Percentile Analysis Scenario
Chester River mainstem	2.552×10^{13}	1.009×10^{14}

4.6 TMDL Loading Caps

This section presents the TMDLs that would meet the median and 90th percentile criteria. Seasonal variability is addressed implicitly through the interpretation of the water quality standards (see Section 4.3). The median and 90th percentile based TMDLs for the restricted shellfish harvesting waters of the Lower Chester River basin are summarized in Table 4.6.1.

Table 4.6.1: Summary of TMDL Loading Caps

Waterbody	Fecal Coliform TMDL [counts per day]	
	based on Median Criterion	based on 90th Percentile Criterion[*]
Chester River mainstem	2.552×10^{13}	3.754×10^{13}

[*] The comparison of the reductions required based on the median and 90th percentile criteria indicated that the 90th percentile scenario requires the largest percent reductions. Therefore, reductions required to meet the 90th percentile criterion provide the basis for the TMDL allocations.

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A five-year averaging period was used to develop the fecal coliform TMDLs for the shellfish harvesting areas in Chester River. This specific averaging period was chosen based on the water quality criteria, which requires at least 30 samples (COMAR 2006). When allocating loads among sources, the scenario that requires the greatest overall reductions (here the 90th percentile scenario) was applied. Table 4.7.1 below summarizes the necessary load reductions by area.

4.7   TMDL Allocations and Percent Reductions

The purpose of this section is to allocate the TMDLs between point (WLA) and nonpoint (LA) sources. As stated in Section 2.4, there are six point source facilities in the reported restricted shellfish harvesting area that have permits to discharge fecal coliform (or E. coli) to the Chester River (or its tributaries) and the fecal coliform load from these point sources is approximately 1.233×10^{10} counts per day and will be included in the WLA. The remaining loads assimilative capacity will be allocated to the load allocation.

The load reduction scenario results in a load allocation by which the TMDL can be implemented to achieve water quality standards. The State reserves the right to revise these allocations, provided the allocations are consistent with the achievement of water quality standards. The load reduction calculated in this document was based on the 90th percentile water quality criterion, which is shown in Table 4.7.1 for the restricted shellfish harvesting area of the Chester River watershed.

Table 4.7.1: Load Reductions

Restricted Shellfish Harvesting Area	Required Reduction
Chester River mainstem	**62.8 %**

Since the load reduction applied to this watershed was based on the 90th percentile water quality standard, it targets only those critical events that occur less frequently. Therefore, the load reduction established is not a literal daily reduction, but rather an indicator that the control of measures for bacterial loads is needed for these more extreme events. Extreme events are often a result of hydrologic variability, land use practices, water recreation uses, or wildlife activities.

4.8   Margin of Safety

A margin of safety is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. For example, knowledge is

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incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of the pollutants on the chemical and biological quality of complex, natural waterbodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

For TMDL development, the MOS needs to be incorporated to account for uncertainty due to model parameter selection. The decay rate is one of the most sensitive parameters in the model. For a given system, the higher the decay rate, the higher the assimilative capacity. The value of the decay rate varies from 0.7 to 3.0 per day in salt water (Mancini, 1978; Thomann and Mueller, 1987). A decay rate of 0.7 per day was used as a conservative estimate in the TMDL calculation. Further literature review supports this assumption as a conservative estimate of the decay rate (MDE 2004). Therefore the MOS is implicitly included in the calculation.

4.9   Summary of Total Maximum Daily Loads

There are five municipal point source facilities: MD0020010 (Chestertown WWTP), MD0052671 (Kennedyville WWTP), MD0023876 (Eastern Pre-Release Unit WWTP), MD0050016 (Church Hill WWTP), and MD0060585 (Worton-Butlerton WWTP) that have NPDES permits regulating the discharge of fecal coliform directly into waters affecting the Chester River and its tributaries. There is also one industrial point source facility: MD0002232 (Chestertown Foods, Inc.) that has a permit to discharge fecal coliform to the Chester River. The fecal coliform loads from these point sources is approximately 1.233×10^{10} counts per day and will be included in the WLA. The remaining loads, calculated based on the most stringent criterion (i.e., the 90th percentile), will be allocated to the load allocation. The TMDL is summarized as follows:

Fecal coliform TMDL (counts per day) based on the 90th percentile criterion:

Area	TMDL	=	LA	+	WLA	+	FA	+	MOS
Chester River mainstem	3.75×10^{13}	=	3.75×10^{13}	+	1.233×10^{10}	+	N/A	+	Implicit

Where:
TMDL = Total Maximum Daily Load
LA   = Load Allocation (Nonpoint Source)
WLA = Waste Load Allocation (Point Source)
FA   = Future Allocation
MOS   = Margin of Safety

5.0   ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurance that the fecal coliform TMDL will be achieved and maintained. The appropriate measures to reduce pollution levels in the impaired segments include, where appropriate, the use of better treatment technology or installation of best management practices. Details of these methods are to be described in the implementation plan.

In general, MDE intends for the required reductions to be implemented in an iterative process that first addresses those sources with the greatest impact on water quality, with consideration given to ease of implementation and cost. The source contributions estimated from the watershed analysis (see Table 2.4.1) may be used as a tool to target and prioritize initial implementation efforts. The iterative approach towards BMP implementation throughout the watershed will help to ensure that the most cost-effective practices are implemented first. The success of BMP implementation will be evaluated and tracked through follow-up stream monitoring.

Existing Funding and Regulatory Framework

Potential funding sources for implementation include Maryland's Agricultural Cost Share Program (MACS), which provides grants to farmers to help protect natural resources, and the Environmental Quality and Incentives Program, which focuses on implementing conservation practices and BMPs on land utilized for livestock and agricultural production. Low interest loans are available to property owners with failing septic systems through MDE's Linked Deposit Program. It is also anticipated that the Bay Restoration Fund will provide funding to upgrade onsite sewage disposal systems with priority given to failing systems and holding tanks in the Chesapeake and Atlantic Coastal Bays Critical Areas. Local governments can utilize funding from the State Water Quality Revolving Loan Fund and the Stormwater Pollution Cost Share Program. Details of these programs and additional funding sources can be found at http://www.dnr.state.md.us/bay/services/summaries.html.

Maryland law requires the following types of facilities to have pumpout stations: existing marinas wishing to expand to a total of 11 or more slips that are capable of berthing vessels that are 22 feet or larger; new marinas with more than 10 slips capable of berthing vessels that are 22 feet or larger; and marinas with 50 or more slips and that berth any vessel over 22 feet in length (Maryland 1996). Any public or private marina in Maryland is eligible to apply for up to $15,000 in grant funds to install a pumpout station through the Maryland Department of Natural Resources.

Regulatory enforcement of potential bacteria sources would be covered by MDE's routine sanitary surveys of shellfish growing areas and NPDES permitting activities. Also, although not directly linked, it is assumed that the nutrient management plans from the Water Quality Improvement Act of 1998 (WQIA) will result in some reduction of bacteria from manure application practices.

As part of Maryland's responsibilities under the NSSP, MDE's Shellfish Certification Program continues to monitor shellfish waters and classify shellfish harvesting areas as restricted, approved, or conditionally approved. A major component of MDE's Shellfish Certification Program is to identify potential pollution sources and correct or eliminate them. Waters meeting shellfish water quality standards are reclassified as approved or conditionally approved harvesting areas. The removal of shellfish harvesting restrictions may serve as a tracking tool measuring water quality improvements. However, when performing such analyses, it is important to understand that MDE may place administrative restrictions or restrictions required by the NSSP. Existence of such restrictions does not necessarily mean that the area is not meeting water quality standards.

Implementation and Wildlife Sources

It is expected that, due to significant wildlife bacteria contribution, some waterbodies will not be able to meet water quality standards even after all anthropogenic sources are controlled. Neither the State of Maryland nor EPA is proposing the elimination of wildlife to allow for the attainment of water quality standards. This is considered to be an impracticable and undesirable action. While managing the overpopulation of wildlife remains an option for State and local stakeholders, the reduction of wildlife or the changing of a natural background condition is not the intended goal of a TMDL.

MDE envisions an iterative approach to TMDL implementation, which first addresses the controllable sources (i.e., human, livestock, and pets) especially those that have the largest impacts on water quality and create the greatest risks to human health, with consideration given to ease the cost of implementation. It is expected that the best management practices applied to controllable sources may also result in reduction of some wildlife sources. Following the initial implementation stage, MDE expects to re-assess the water quality to determine if the designated use is being attained. If the water quality standards are not attained, other sources may need to be controlled. However, if the required controls go beyond maximum practical reductions, MDE might consider developing either a risk-based adjusted water quality assessment or a Use Attainability Analysis to reflect the presence of naturally high bacteria levels from uncontrollable (natural) sources.

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Appendix A. Model Development

The 3-dimensional hydrodynamic and eutrophication model (HEM-3D) has been used for this study. The HEM-3D model is a general 3D model for environmental studies. The model simulates density and topographically induced circulation as well as tidal and wind-driven flows, spatial and temporal distributions of salinity, temperature, and suspended sediment concentrations, conservative tracers, eutrophication processes, and fecal coliform. The model has been applied for varieties of environmental problems in estuaries (Hamrick 1992a; Shen, Boon, and Kuo 1999). For a detailed discussion of the model theory, readers are referred to Hamrick (1992b).

Figure A-1 is the model grid superimposed on the 24 subwatersheds of the Chester River. The modeling domain consists of 207 grid cells. Because the Chester River is narrow in its upstream portion, a one-dimensional model grid was used to represent the river in the upstream portion of the river whereas a two-dimensional model grid was used in the downstream portion of the river. The model open boundary is placed approximately 10 km downstream of the restricted area. To better simulate estuarine circulation, a total of 3 layers were used in the vertical. The fecal coliform was simulated using a conservative tracer with first-order decay. The decay rate varies from 0.7 to 3.0 per day in salt water (Mancini 1978; Thomann and Mueller 1987). A decay rate of 0.7 per day was used as a conservative estimate in this TMDL study.

The Chester River is a tidal river. The dominant tidal constituent is M_2 (lunar semi-diurnal tide). To simulate tide correctly, a calibration of mean tide was conducted. The model was forced by an M_2 tide with the mean tidal range of 0.55 m at the model open boundary. The model results are compared with the National Oceanic and Atmospheric Administration (NOAA) predicted tides at four stations inside the Chester River (NOAA 2006). The locations of these stations are shown in Figure A-2. The model results and observed tidal ranges are listed in Table A-1. The HEM-3D model results compare well with results reported from the tidal table. The model simulation of salinity was calibrated based on the mean salinity obtained from monitoring stations along the river. The locations of these stations are shown in Figure A-2. For the mean salinity calibration, the dominant M_2 tide was used as a forcing at the model open boundary. Mean salinity measured at the station nearest the mouth was used as the salinity boundary condition. The quantity of freshwater discharged from each subwatershed was estimated according to the average long-term flow from the USGS gage of 01493500 (Morgan Creek near Kennedyville, MD). The flow of each subwatershed was estimated based on the ratio of the subwatershed area to the drainage basin area of the USGS gage. The mean flows used for the model calibration are listed in Table A-2 below for the subwatersheds shown in Figure A-1. A comparison of model results against observations is shown in Figure A-3. It can be seen that the model simulation of salinity distribution is satisfactory in the estuary.

Since the water quality criteria for fecal coliform are expressed in terms of the median and the 90th percentile concentrations, the modeling tasks are to estimate fecal coliform mean daily loads from the watershed corresponding to the median and 90th percentile, respectively. For a

relatively small waterbody, the tidal prism model has been used to estimate the loads based on the observations and water quality standards using the inverse method (or back calculation) (MDE 2005). For this study, an inverse modeling approach method built on the HEM-3D has been used to estimate fecal coliform loading from the watershed. The purpose of the inverse modeling is to estimate the long-term average daily loads corresponding to the median and 90th percentile concentrations in the waterbody. Therefore, the fecal coliform daily loads from each subwatershed can be considered as constant model parameters. The inverse methods have been used for many environmental problems to estimate point source loads and model parameters (Shen and Kuo 1996; Sun and Yeh 1990; Shen 2006).
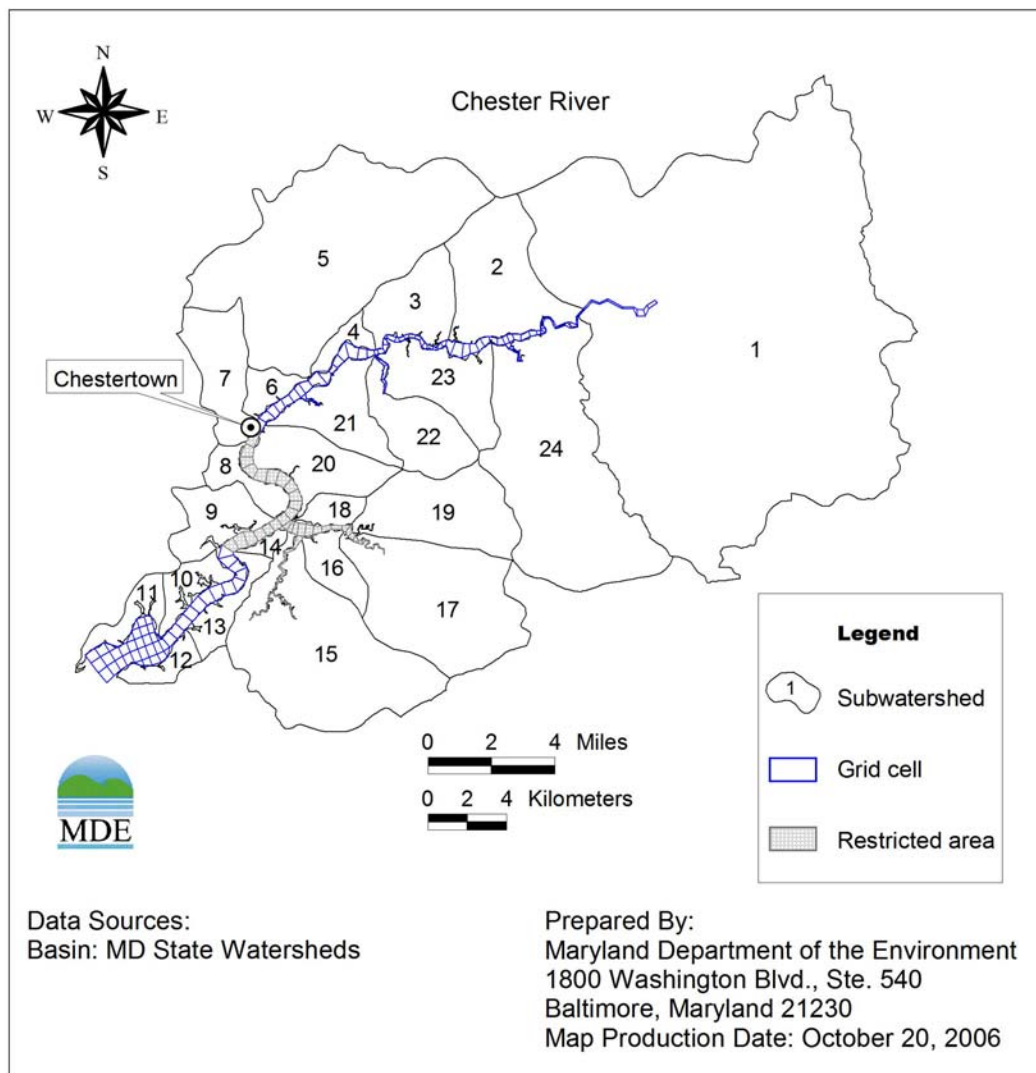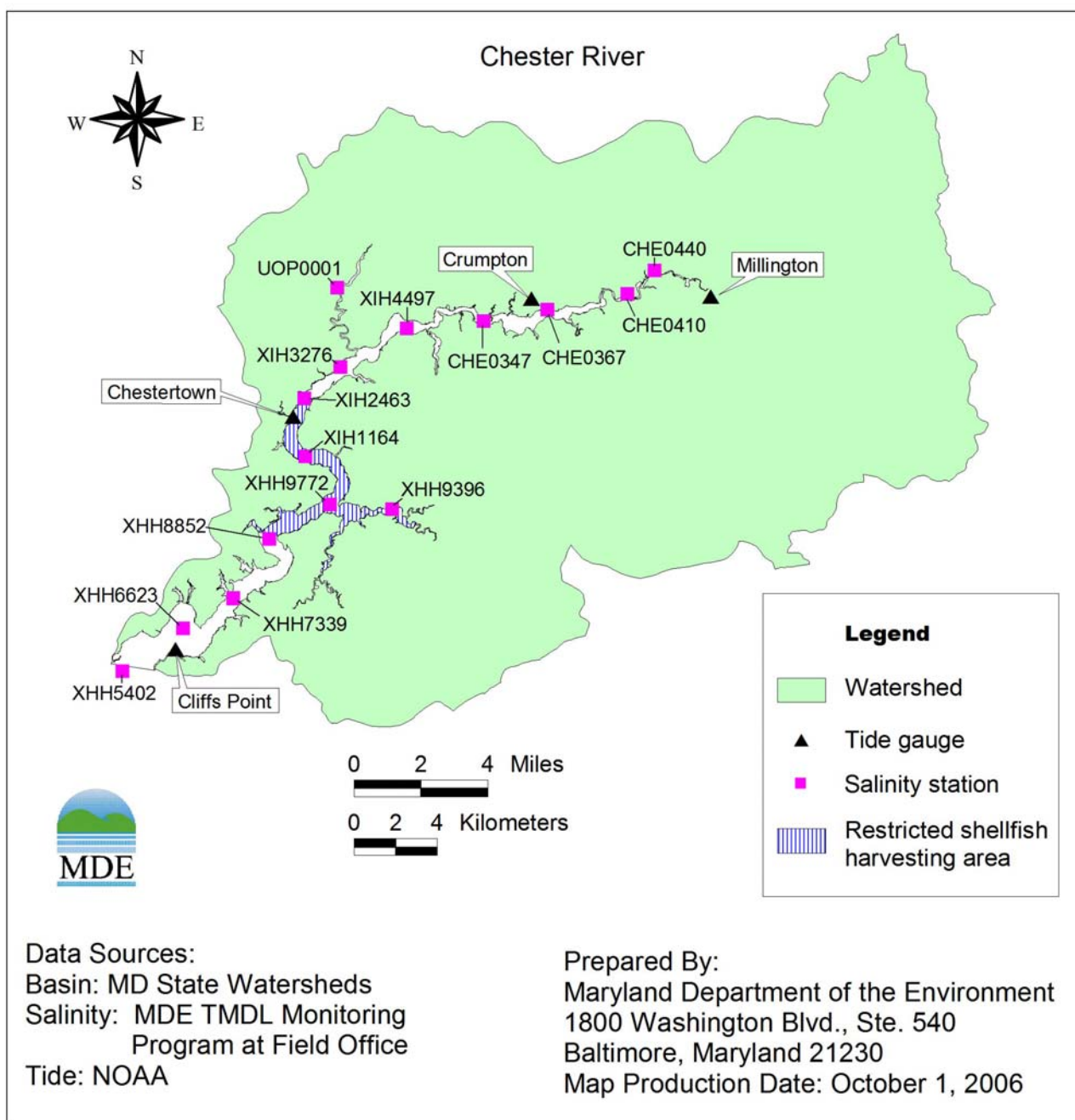

Figure A-1: HEM-3D Grid Cells and Subwatersheds in the Chester River

Table A-1: Comparison of Modeled and NOAA Predicted Mean Tidal Range

Station	Modeled Range (m)	NOAA Predicted Range (m)
Cliffs Point	0.466	0.457
Chestertown	0.569	0.548
Crumpton	0.641	0.732
Millington	0.617	0.610

Table A-2: Estimated Mean Flows of Subwatersheds in the Chester River

Subwatershed	Mean Flow (cms)
1	2.887
2	0.285
3	0.150
4	0.035
5	0.855
6	0.044
7	0.161
8	0.062
9	0.115
10	0.059
11	0.061
12	0.044
13	0.065
14	0.015
15	0.547
16	0.071
17	0.431
18	0.041
19	0.253
20	0.158
21	0.146
22	0.159
23	0.178
24	0.685

Figure A-2: Tide and Salinity Stations of the Chester River Used in Model Calibration
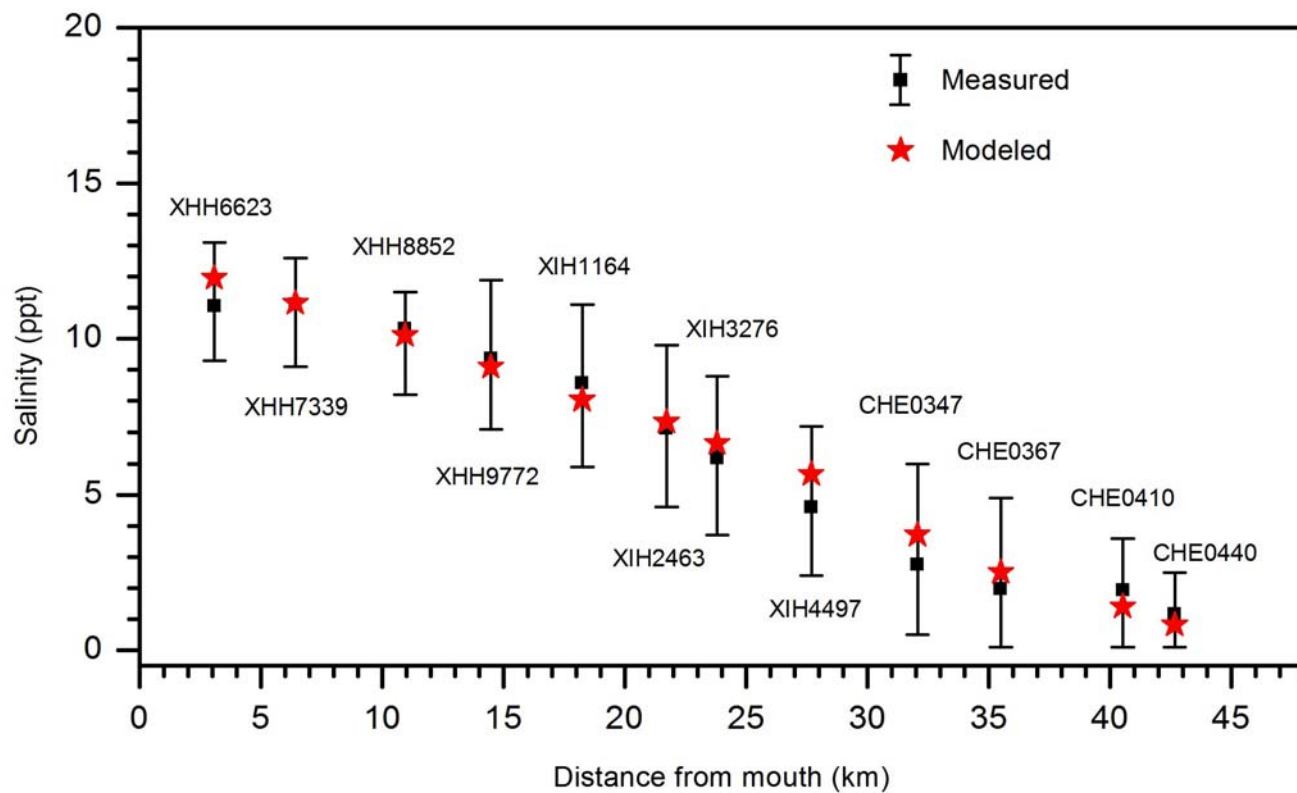
Figure A-3: Comparison of Measured and Calculated Salinities

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The problem of loads estimation can be treated as an inverse problem: to find a set of loads such that a defined goal function (or cost function), which measures the data misfit between the model predictions and the observations, becomes minimal. It can be presented as follows:

$$J(\mathbf{C};\boldsymbol{\beta}^*) = \min J(\mathbf{C};\boldsymbol{\beta}) \tag{1}$$

subject to:

$$\boldsymbol{\beta}^* \in \boldsymbol{\beta}_0 \tag{2}$$
$$\mathbf{F} = 0 \tag{3}$$

where J is a goal or cost function; $\boldsymbol{\beta}^* =(\beta_1,\beta_2, ...,\beta_m)$ is the optimal parameter (*i.e.*, loads); $\boldsymbol{\beta}_0$ is an acceptable set of loads. $\mathbf{F}$ is transport function. Different methods can be used to characterize the noninferior solutions. Choosing a weighted least-square criterion to measure the data misfit, the scalar cost function is then defined as follows:

$$J(\mathbf{C};\boldsymbol{\beta}) = \int_{T_N} \int\int_{\Omega} \frac{w}{2}(C(x,z,t) - C^0(x,z,t))^2 d\Omega dt \tag{4}$$

where C and C^0 are modeled and measured fecal coliform in the river, Ω is the spatial domain in the x- and z- directions, T_N is time later than the last date when the prototype observations are available, and w is the weight. In our case, let $C_m(x)$ be the median or 90th percentile obtained from the observations at location (x). If we choose:

$$C_m(x) = \max(C(x,z,t)) \quad for \quad T_0 < t < T_N \tag{5}$$

Equation (4) can be written as:

$$J(\mathbf{C};\boldsymbol{\beta}) = \int_X \frac{w}{2}(C_m(x,t) - C_m^0(x))^2 dx \tag{6}$$

The algorithm can be constructed as a sequence of the unconstrained minimization problem. Many authors have studied the solution of the optimization problem extensively. Several different methods can be used to solve the problem including the Gradient method, Conjugate direction method, and the Variational method (Bertsekas 1995). For this study, the modified Newton method was used to solve the optimization problem (Shen 2006).

The fecal coliform loads discharged to the river originate from 24 subwatersheds, as shown in Figure A-1. There is only one station located inside the restricted area and two stations located downstream of the restricted area of the model domain. To better estimate the existing load, a

short-term bi-weekly monitoring was conducted from September to December 2005. Because the data series is not long enough to compute the median and 90th percentile values directly, the ratio method was used to estimate these values at these short-term stations. For the long-term monitoring station inside the restricted area, the ratios of mean and maximum values are obtained from short-term observations and the corresponding median and 90th percentile values for long-term observations are computed. The ratios were applied to other stations upstream to estimate the median and 90th percentile values at those stations. Although this approach may deviate from the true values of median and 90th percentile, the estimated results can be expected to be within the same range and are suitable for the model calibration. For the estimation of existing median loads, the model was forced by an M_2 tide and mean salinity at the mouth. The mean freshwater inflows from the subwatersheds are discharged into the river. A set of initial loads from 24 subwatersheds was estimated and discharged to the river. The initial loads are estimated based on the land use type and drainage sizes. The model was run for 60 days to reach equilibrium and the maximum concentration on the last day was used to calculate the cost function against the observed median along the river. Chester River mainstem fecal coliform long-term monitoring stations and short-term survey stations are shown in Figure A-4. The modified Newton method was used to update the loads until the cost function is minimum. For estimating the existing loads for 90th percentile, the same method was used except the existing 90th percentile concentrations were used to minimize the cost function.
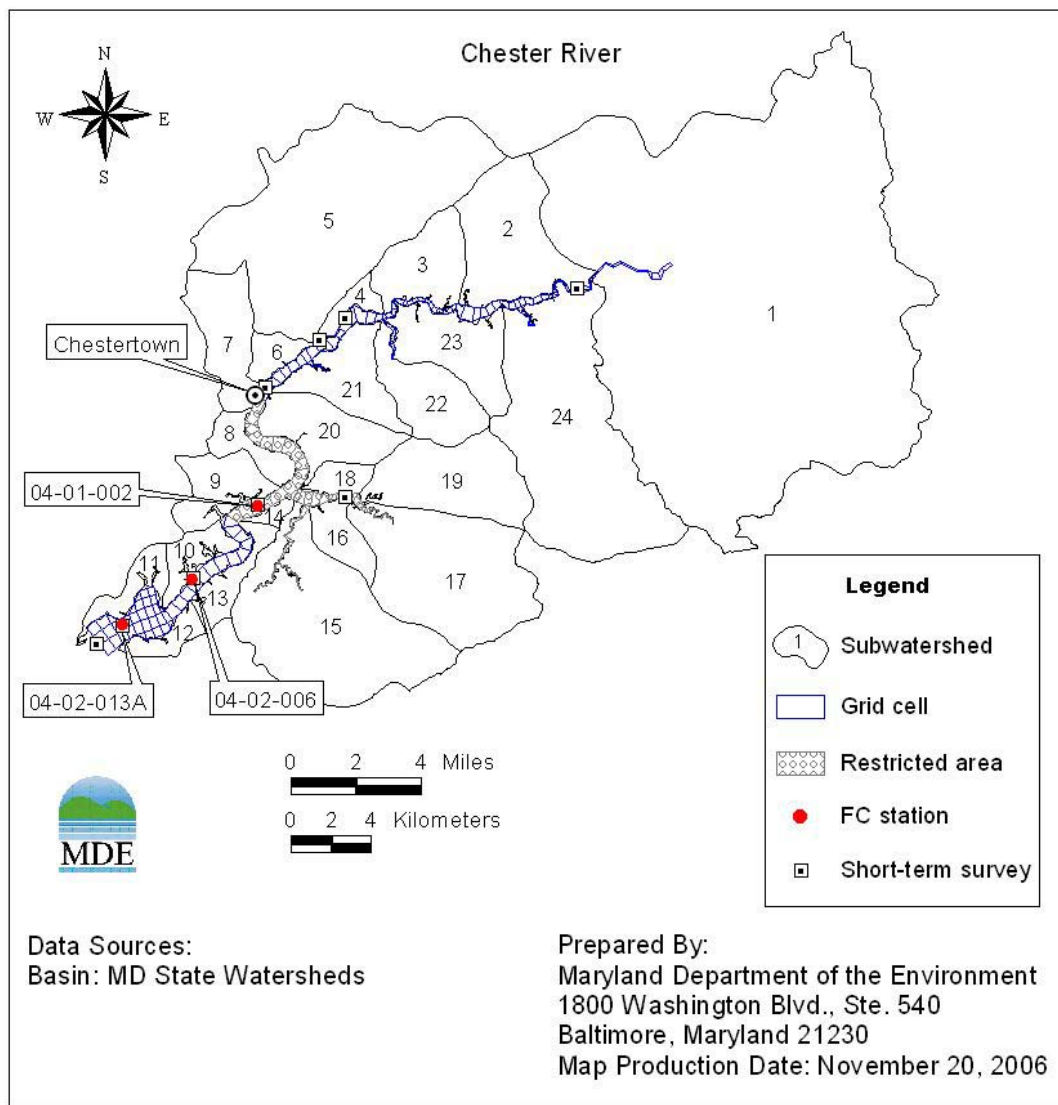
Figure A-4: Locations of Chester River Fecal Coliform Monitoring Stations

Figures A-5 and A-6 show the model results of the simulated median and 90th percentile, respectively, along the river. It can be seen that the model results are satisfactory. The model results and observations at long-term monitoring stations are listed in Table A-3. It can be seen that the results are satisfactory. The existing loads for each subwatershed are listed in Table A-4.

In the upstream of the Chester River mainstem, a large portion of the watersheds is located in Delaware. To evaluate the contribution of fecal coliform loading to the downstream restricted area, a model sensitivity run was conducted by discharging fecal coliform with a high concentration of 3000 MPN/100ml at the headwater. The fecal coliform along the river is shown

in Figure A-7. It can be seen that the fecal coliform concentration reduces to less than 1 MPN at the upper boundary of the restricted area. This suggests that most of the fecal coliform is lost during the transport due to decay resulting in less contribution to the high fecal coliform concentration that is found in the restricted area. Therefore, no fecal coliform reduction from the headwater portion of Chester River is considered for the TMDL calculation.

For the TMDL calculation, the 90th percentile loads from the watershed adjacent to the restricted area and the watershed upstream of the area were reduced so that the model simulated fecal coliform values along the river that meet the median and 90th percentile criteria. The resultant loads are the allowable loads for the river. With the use of existing loads and TMDLs, the percentage reduction can be estimated. Since there is no violation of median concentration of fecal coliform, the load reduction is not required. Therefore, the existing median load is used as the TMDL. Comparing the reduction needed for both median and 90th percentile loads, the maximum reductions required for each watershed are used to establish the TMDLs. The existing and allowable loads are listed in Table A-4. Note that the current median loads are used as allowable loads.

Table A-3: Model Calibration Results for Fecal Coliform Concentration in Chester River

Station	Median (MPN/100 mL)		90th percentile (MPN/100 mL)	
	Measured	Modeled	Measured	Modeled
04-01-002*	9.1	9.1	78.6	82.9
04-02-006**	9.1	9.4	54.5	56.2
04-02-013A	3.6	3.8	40.9	38.2

* Station 04-01-002 is located inside the restricted shellfish harvesting area
** Station 04-02-006 is a conditionally approved station for which the criteria are met during the period when this area is open to harvesting

Table A-4: TMDL Calculation Results for Each Subwatershed

Subwatershed	Median			90th Percentile		
	Allowable Load*	Current Load	Percent Reduction	Allowable Load	Current Load	Percent Reduction
	Counts/day	Counts/day		Counts/day	Counts/day	
1, 2, 24	1.191E+13	1.191E+13	0%	1.449E+13	1.449E+13	0.00%
3-8, 20-23	8.926E+12	8.926E+12	0%	9.867E+12	6.048E+13	83.69%
15-19	1.124E+12	1.124E+12	0%	1.213E+12	1.224E+13	90.09%
9-14	3.564E+12	3.564E+12	0%	1.196E+13	1.369E+13	12.64%
TOTALS	2.552E+13	2.552E+13	NA	3.754E+13	1.009E+14	62.79%

* No reduction was required for the median analysis. Here, the current load was used for the allowable load.

DRAFT

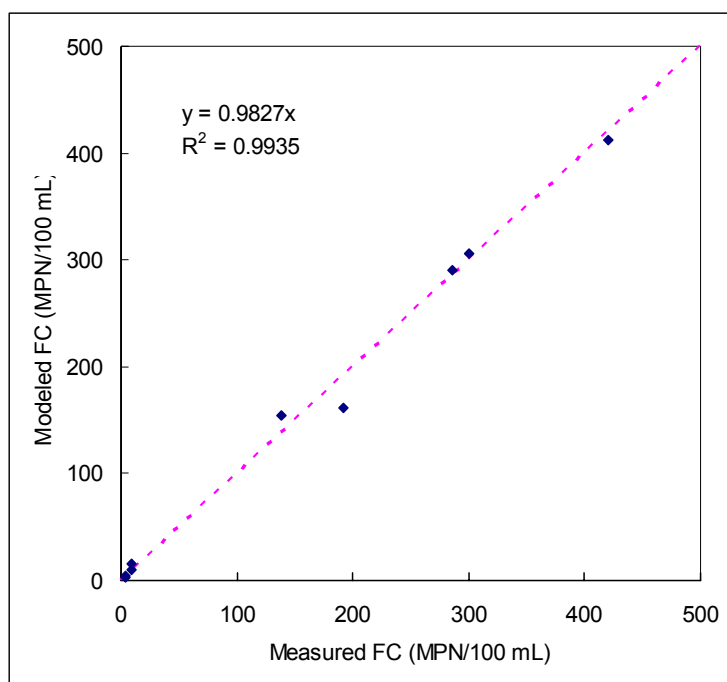**Figure A-5: Measured and Modeled Fecal Coliform for the Median Criterion (note: measurement data shown includes both long-term and short-term)**
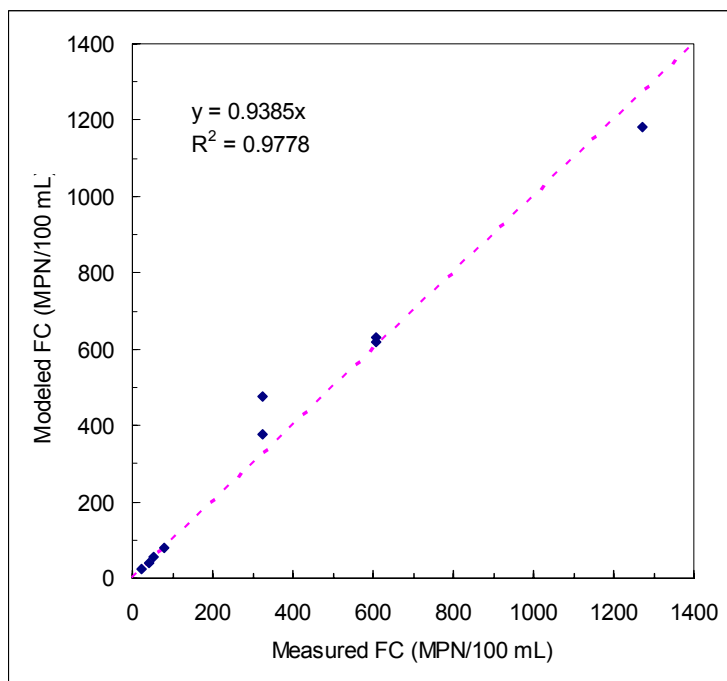

Figure A-6: Measured and Modeled Fecal Coliform for the 90th Percentile Criterion (note: measurement data shown includes both long-term and short-term)

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By comparing the reductions required for the median and 90th percentile, one can see that the 90th percentile requires the largest reduction. Therefore, the reductions required to meet the 90th percentile at each subwatershed are the overall reductions required for the subwatersheds. The allowable loads and required reductions for the watershed are listed in Table A-5.

Table A-5: Load Allocation and Reduction by Subwatershed

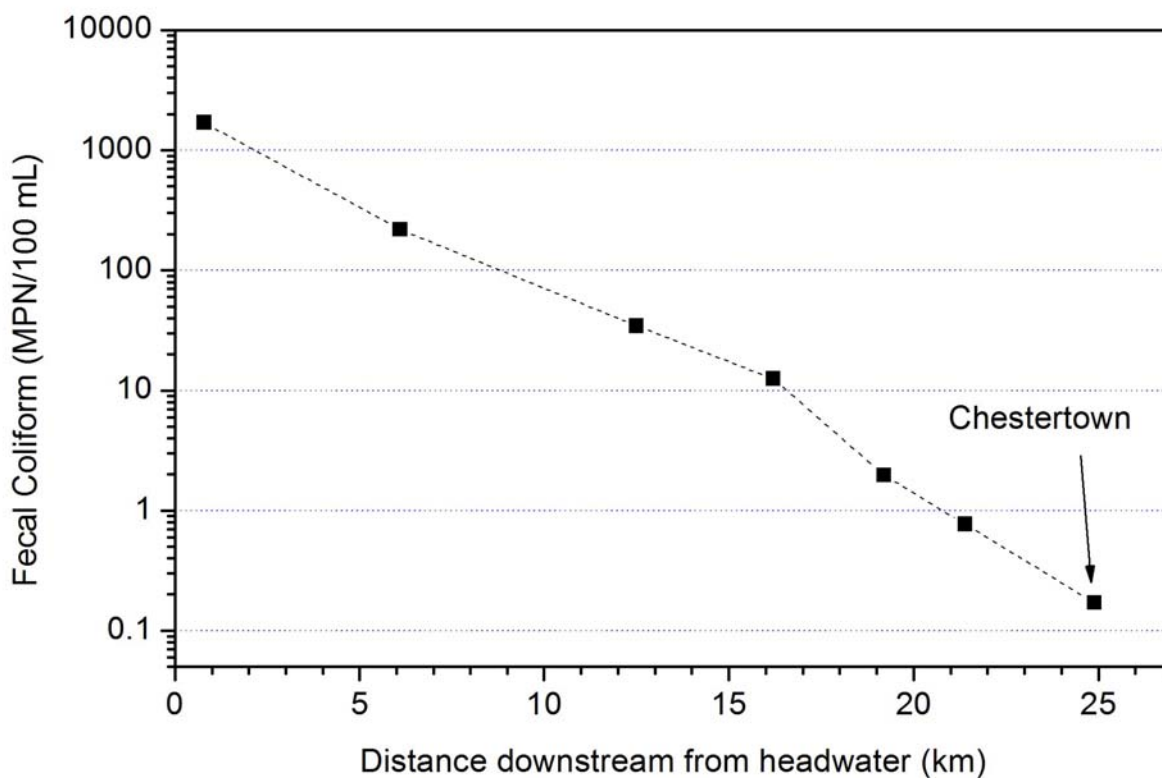| Subwatershed	Load Allocation	Required Reduction
1, 2, 24	1.449E+13	0.00%
3-8, 20-23	9.867E+12	83.69%
15-19	1.213E+12	90.09%
9-14	1.196E+13	12.64%
TOTALS	3.754E+13	62.79%

Figure A-7: Fecal Coliform Concentrations along Chester River

Appendix B. Bacteria Source Tracking

Nonpoint sources of fecal coliform do not have one discharge point and may occur over the entire length of a stream or waterbody. The possible introductions of fecal coliform bacteria to the land surface are through the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. As the runoff occurs during rain events, surface runoff transports water and fecal coliform over the land surface to surface waters. Nonpoint source contributions to the bacteria levels from human activities generally arise from failing septic systems from recreation vessel discharges. The transport of fecal coliform from land surface to shellfish harvesting areas is dictated by the hydrology, soil type, land use, and topography of the watershed.

In order to determine the significant sources of fecal coliform and reduction needed to achieve water quality criteria among these sources, it is necessary to identify all existing sources. The nonpoint source assessment was conducted using the fecal coliform monitoring data (provided by MDE Shellfish Certification Programs) and bacteria source tracking analysis to quantify source loadings from humans, livestock, pets, and wildlife.

Bacteria Source Tracking

In order to assess the potential fecal bacteria sources that contribute to the Chester River, one routine monitoring station in the Chester River was selected to evaluate the source characterization through a process called Bacteria Source Tracking (BST). BST is used to provide evidence regarding contributions from anthropogenic sources (*i.e.*, human or livestock) as well as background sources, such as wildlife. Twelve months of sampling was conducted from November 2005 to October 2006. Antibiotic Resistance Analysis (ARA) was the chosen BST method used to determine the potential sources of fecal coliform in the Chester River. ARA uses enterococci or *Escherichia coli* (*E. coli*) and patterns of antibiotic resistance to identify sources. The premise is that the antibiotic resistance of bacteria isolated from different hosts can be discerned based upon differences in the selective pressure of microbial populations found in the gastrointestinal tract of those hosts (humans, livestock, pets, wildlife) (Wiggins 1996). Bacteria isolated from the fecal material of wildlife would be expected to have a much lower level of resistance to antibiotics than bacteria isolates collected from the fecal material of humans, livestock and pets. In addition, depending upon the specific antibiotics used in the analysis, isolates from humans, livestock and pets could be differentiated from each other.

In ARA, isolates from known sources are tested for resistance or sensitivity against a panel of antibiotics and antibiotic concentrations. This information is then used to construct a library of antibiotic resistance patterns from known-source bacterial isolates. Enterococci isolates were obtained from known source present in the watershed. For the Chester River, these known sources included human, livestock (cow, horse), pet (dog) and wildlife (deer, duck, fox, goose, muskrat, rabbit, seagull). Bacterial isolates collected from water samples are then tested and their resistance results are recorded. Based upon a comparison of resistance patterns of water and

known library isolates, a statistical analysis can predict the likely host source of the water isolates. (Hagedorn 1999; Wiggins 1999).

A tree classification method, [1]CART®, was applied to build a model that classifies isolates into source categories based on ARA data. CART® builds a classification tree by recursively splitting the library of isolates into two nodes. Each split is determined by the antibiotic variables (antibiotic resistance measured for a collection of antibiotics at varying concentrations). The first step in the tree-building process splits the library into two nodes by considering every binary split associated with every variable. The split is chosen in order to maximize a specified index of homogeneity for isolate sources within each of the nodes. In subsequent steps, the same process is applied to each resulting node until a *stopping* criterion is satisfied. Nodes where an additional split would lead to only an insignificant increase in the *homogeneity index* relative to the *stopping* criterion are referred to as *terminal* nodes.[2] The collection of *terminal* nodes defines the classification model. Each *terminal* node is associated with one source, the source that is most populous among the library isolates in the node. Each water sample isolate (*i.e.*, an isolate with an unknown source), based on its antibiotic resistance pattern, is identified with one specific *terminal* node and is assigned the source of the majority of library isolates in that *terminal* node.[3] The full BST report for the Chester River basin is located in Frana and Venso (2007).

Results

Water samples were collected monthly from the one routine monitoring station in the Chester River. The maximum number of *Enterococcus* isolates per water sample was 24, although the number of isolates that actually grew was sometimes less than 24. A total of 95 *Enterococcus* isolates were analyzed by statistical analysis. Table B-1 below shows the ARA results by category, the number of isolates and percent isolates classified at the 0.60 (60%) cutoff probability, as well as the percent classified overall. The seasonal distribution of water isolates from samples collected at each sampling station is shown below in Table B-2. According to the ARA, livestock is the predominant bacteria source followed by pet, wildlife and human. Forty-two percent (42%) of the water isolates were from unknown (unclassified) probable sources.

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[1] The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Hastie T, Tibshirani R, and Friedman J. Springer 2001.

[2] An ideal split, i.e., a split that achieves the theoretical maximum for homogeneity, would produce two nodes each containing library isolates from only one source.

[3] The CART® tree-classification method we employed includes various features to ensure the development of an optimal classification model. For brevity in exposition, we have chosen not to present details of those features, but suggest the following sources: Breiman L, et al. *Classification and Regression Trees.* Pacific Grove: Wadsworth, 1984; and Steinberg D and Colla P. *CART—Classification and Regression Trees.* San Diego, CA: Salford Systems, 1997.

Table B-1: Probable Host Sources of Water Isolates by Category, Number of Isolates, Percent Isolates Classified at Cutoff Probabilities of 60%

Category	No.	% Isolates Classified (60% Prob.)	% Isolates Classified without unknown source
Pet	17	17.9%	30.9%
Human	8	8.4%	14.5%
Livestock	19	20.0%	34.5%
Wildlife	11	11.6%	20.0%
*Unknown	40	42.1%	
Total	95		
% Classified		57.9%	100%

* Unknown means that the library of known sources failed to classify for isolates from water samples collected

Table B-2: Number of Enterococci Isolates from Water Collected and Analyzed by Season

Station	Spring	Summer	Fall	Winter	Total
04-01-002	17	28	34	16	95
Total	17	28	34	16	95

Appendix C. Seasonality Analysis

The Code of Federal Regulations requires that TMDL studies take into account critical conditions for stream flow, loading, and water quality parameters (CFR 2006c). The Environmental Protection Agency (EPA) also requires that these Total Maximum Daily Load (TMDL) studies take into account seasonal variations. The consideration of critical condition and seasonal variation is to account for the hydrologic and source variations. The intent of the requirements is to ensure that the water quality of the water body is protected during the most vulnerable times.

In the Chesapeake Bay region, both fecal coliform sources and delivery vary seasonally due to changes in hydrological conditions and land use practices. The most probable fecal coliform sources are runoff from agricultural practices and livestock, wildlife, and developed areas. Precipitation and temperature fluctuate seasonally, producing varied stream flow and surface runoff that serve as a delivery mechanism for fecal coliform, as well as seasonal changes in vegetation. Vegetation, particularly in pastureland and agricultural buffer zones, is very important for trapping and preventing fecal coliform from entering waters by decreasing surface runoff. Wildlife are active during summer and fall due to ample food supply, resulting in increased fecal coliform production, and the probability of their direct contact with receiving waters is comparatively high during warm seasons. The seasonal variation of fecal coliform concentrations in water not only results from activities of wildlife on forestland and wetland, but it is also related to agricultural activities. Fecal coliform deposition on a field by livestock can be transported into streams and rivers through surface runoff, and thus there tends to be an increase in fecal coliform concentrations during wet seasons. In croplands, fecal coliform discharge is often related to the timing of crop planting and fertilization. Improper manure application during crop planting may increase the risk of exceeding fecal coliform standards in the receiving water. Such seasonal changes in both the sources and the delivery mechanisms of fecal coliform may lead to obvious seasonal patterns in fecal coliform concentration in the shellfish growing areas.

A five-year monthly mean fecal coliform concentration and its standard deviation were calculated for the one monitoring station used in this report. The results are presented in Figure C-1. It shows that high fecal coliform concentrations occur in the months of September and November in the Chester River. Although seasonal distributions vary from one month to the next, a large standard deviation that corresponds to the high fecal coliform concentration variability at each station suggests that the violation, in regards to the criteria, may occur in a few months of the year.
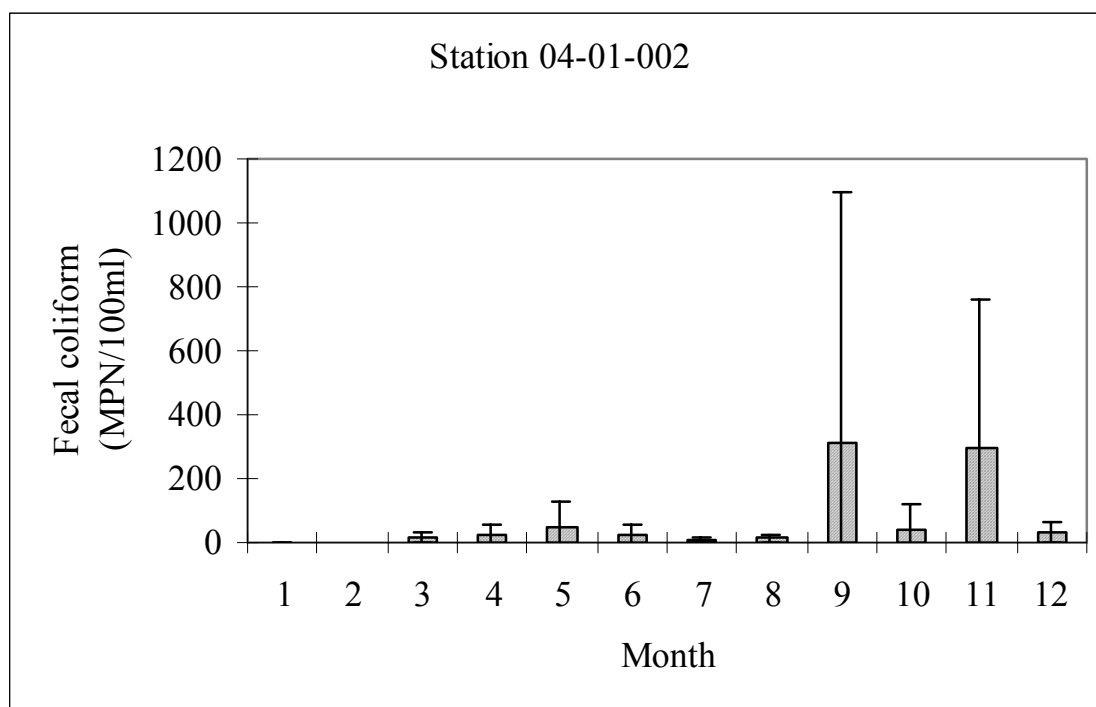
Figure C-1: Seasonality Analysis of Fecal Coliform at Chester River Station 04-01-002

Appendix D. Tabulation of Fecal Coliform Data

This appendix provides a tabulation of fecal coliform values for the monitoring station of the restricted shellfish harvesting area in Chester River in Table D-1. These data are plotted in Figure 2.2.2 of the main report.

Table D-1: Observed Fecal Coliform Data at Chester River Station 04-01-002

DATE	Fecal Coliform MPN/100 ml	DATE	Fecal Coliform MPN/100 ml
6/15/2000	93	4/15/2003	9.1
6/27/2000	3.6	5/1/2003	7.3
7/17/2000	9.1	5/12/2003	3.6
9/13/2000	9.1	6/9/2003	93
10/12/2000	9.1	6/26/2003	23
12/6/2000	9.1	7/14/2003	3
1/30/2001	1	8/12/2003	3.6
4/25/2001	9.1	8/25/2003	3.6
6/12/2001	3.6	9/10/2003	3.6
6/26/2001	3.6	9/24/2003	2400
8/2/2001	9.1	11/19/2003	23
8/16/2001	23	4/14/2004	3.6
9/26/2001	43	4/27/2004	93
10/11/2001	1	5/10/2004	3.6
10/29/2001	9.1	5/25/2004	23
11/14/2001	23	6/9/2004	9.1
12/19/2001	9.1	6/23/2004	9.1
1/14/2002	1	7/13/2004	23
3/14/2002	3.6	7/21/2004	3.6
4/9/2002	3.6	8/11/2004	23
5/20/2002	240	8/26/2004	23
6/25/2002	1	9/2/2004	3.6
7/9/2002	3.6	9/14/2004	3.6
7/31/2002	9.1	9/22/2004	7.5
8/20/2002	3.6	10/14/2004	240
9/23/2002	7.3	10/27/2004	15
10/8/2002	3.6	11/17/2004	43
10/28/2002	23	3/7/2005	1
11/19/2002	1100	4/12/2005	9.1
12/12/2002	75	5/10/2005	9.1
1/16/2003	3.6	5/31/2005	23
3/4/2003	43	6/16/2005	9.1